

Chemistry of life

General Microbiology - Lecture 2

Cañada College, Redwood City - Fall 2008

Instructor: Tamas Torok, Ph.D.

Topics for today

- **(Very) basic chemistry terms**
- **Biologically important**
 - bonds
 - reactions
 - molecules/polymers/macromolecules

Unity of life

- **Cellular organization**
 - cell - a dynamic entity that forms the fundamental unit of life
- **Same macromolecules do basically the same chemical processes in an open, non-equilibrium system**
- **Living organisms accumulate and recycle elements of their environment**

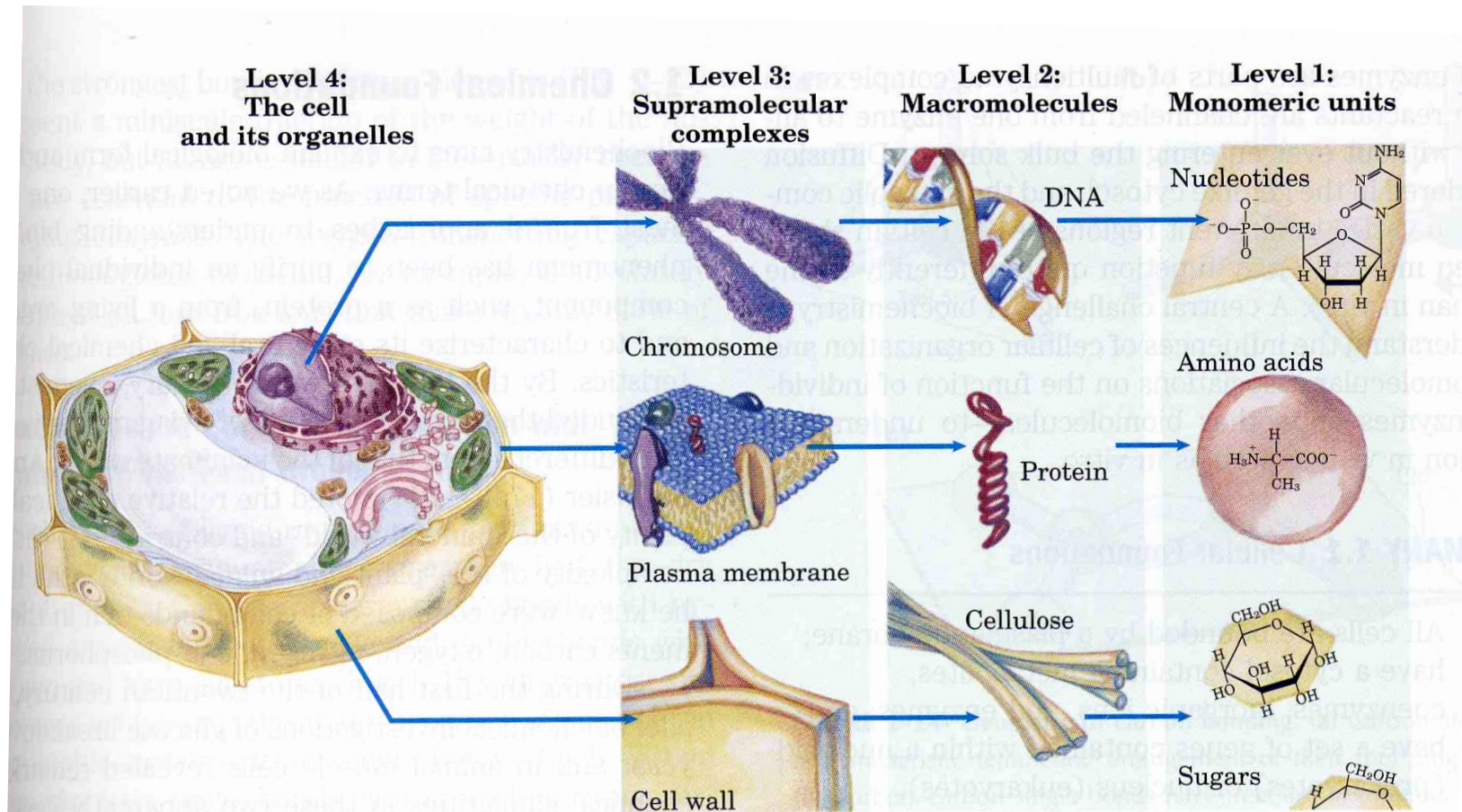
Characteristics of living systems

- **Compartmentalization and metabolism**
 - chemical transformation of nutrients
- **Regeneration**
 - repair and replacement of components
- **Reproduction**
 - generation of two cells from one
- **Differentiation**
 - synthesis of new substances or structures that modify the cell (only in some microbes)

Characteristics of living systems

- **Communication**
 - generation of, and response to, chemical signals
- **Movement**
 - via self-propulsion, many forms in microbes
- **Evolution**
 - genetic changes in cells that are transferred to offspring

Cellular organization/ same macromolecules



Ten most abundant elements in the Earth's crust

Element	Abundance [% by weight]	Abundance [ppm by weight]
Oxygen	46.1%	461,000
Silicon	28.2%	282,000
Aluminum	8.23%	82,300
Iron	5.63%	56,300
Calcium	4.15%	41,500
Sodium	2.36%	23,600
Magnesium	2.33%	23,300
Potassium	2.09%	20,900
Titanium	0.565%	5,650
Hydrogen	0.14%	1,400

CRC Handbook of Chemistry and Physics, 77th Edition

7

Elements of life

- Life accumulates less abundant elements
 - carbon
 - nitrogen
 - sulfur
 - phosphorus
 - trace elements

TABLE 1-2 Molecular Components of an *E. coli* Cell

	Percentage of total weight of cell	Approximate number of different molecular species
Water	70	1
Proteins	15	3,000
Nucleic acids		
DNA	1	1
RNA	6	>3,000
Polysaccharides	3	5
Lipids	2	20
Monomeric subunits and intermediates	2	500
Inorganic ions	1	20

Structure of atoms

- Atoms are the smallest units of matter that can enter into chemical reactions
- Every atom has a centrally located nucleus surrounded by electrons arranged in an electron configuration
- Sub-atomic particles
 - proton - relative mass: 1; relative charge: +
 - neutron - relative mass: 1; relative charge: none
 - electron - relative mass: 1/1836; relative charge: -
 - # of electrons is equal to the # of protons

Chemical elements

- **Atoms with the same number of protons behave chemically the same way and are classified as the same chemical element**
- **Atomic number** - # of protons
- **Atomic mass** - # of protons + # of neutrons
- **Isotopes** - # of neutrons varies

Periodic table of elements

PERIODIC TABLE

Atomic Properties of the Elements

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Frequently used fundamental physical constants

For the most accurate values of these and other constants, visit physics.nist.gov/constants
1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of ^{133}Cs

speed of light in vacuum	c	299 792 458 m s^{-1} (exact)
Planck constant	h	$6.6261 \times 10^{-34} \text{ J s}$ ($h = h/2\pi$)
elementary charge	e	$1.6022 \times 10^{-19} \text{ C}$
electron mass	m_e	$9.1094 \times 10^{-31} \text{ kg}$
	$m_e c^2$	0.5110 MeV
proton mass	m_p	$1.6726 \times 10^{-27} \text{ kg}$
fine-structure constant	α	1/137.036
Rydberg constant	R_∞	$10 973 732 \text{ m}^{-1}$
	$R_\infty c$	$3.289 842 \times 10^{15} \text{ Hz}$
	$R_\infty h c$	13.6057 eV
Boltzmann constant	k	$1.3807 \times 10^{-23} \text{ J K}^{-1}$

□ Solids
□ Liquids
□ Gases
□ Artificially Prepared

Physics Laboratory
physics.nist.gov

Standard Reference Data Group
www.nist.gov/stdref

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	IA	IIA	IIIB	IVB	VB	VIB	VII	VIII	IX	X	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	H Hydrogen 1.00794 1s																	He Helium 4.002602 1s
2	Li Lithium 6.941 1s ² 2s	Be Beryllium 9.012182 1s ² 2s ²																Ne Neon 20.1797 1s ² 2s ² 2p ⁶
3	Na Sodium 22.989770 [Ne]3s	Mg Magnesium 24.3050 [Ne]3s ²											B Boron 10.811 1s ² 2s ² 2p	C Carbon 12.0107 1s ² 2s ² 2p ²	N Nitrogen 14.0067 1s ² 2s ² 2p ³	O Oxygen 15.9994 1s ² 2s ² 2p ⁴	F Fluorine 18.9984032 1s ² 2s ² 2p ⁵	Ar Argon 39.948 [Ne]3s ² 3p ⁶
4	K Potassium 39.0983 [Ar]4s	Ca Calcium 40.078 [Ar]4s ²	Sc Scandium 44.955910 [Ar]3d ¹ 4s ²	Ti Titanium 47.887 [Ar]3d ² 4s ²	V Vanadium 50.9415 [Ar]3d ³ 4s ²	Cr Chromium 51.9961 [Ar]3d ⁵ 4s ¹	Mn Manganese 54.938049 [Ar]3d ⁵ 4s ²	Fe Iron 55.845 [Ar]3d ⁶ 4s ²	Co Cobalt 58.933200 [Ar]3d ⁷ 4s ²	Ni Nickel 58.6934 [Ar]3d ⁸ 4s ²	Cu Copper 63.546 [Ar]3d ¹⁰ 4s ¹	Zn Zinc 65.409 [Ar]3d ¹⁰ 4s ²	Ga Gallium 69.723 [Ar]3d ¹⁰ 4s ² 4p ¹	Ge Germanium 72.64 [Ar]3d ¹⁰ 4s ² 4p ²	As Arsenic 74.92160 [Ar]3d ¹⁰ 4s ² 4p ³	Se Selenium 78.96 [Ar]3d ¹⁰ 4s ² 4p ⁴	Br Bromine 79.904 [Ar]3d ¹⁰ 4s ² 4p ⁵	Kr Krypton 83.796 [Ar]3d ¹⁰ 4s ² 4p ⁶
5	Rb Rubidium 85.4678 [Kr]5s	Sr Strontium 87.62 [Kr]5s ²	Y Yttrium 88.90585 [Kr]4d ¹ 5s ²	Zr Zirconium 91.224 [Kr]4d ² 5s ²	Nb Niobium 92.90638 [Kr]4d ⁴ 5s ¹	Mo Molybdenum 95.94 [Kr]4d ⁵ 5s ¹	Tc Technetium (98) [Kr]4d ⁵ 5s ²	Ru Ruthenium 101.07 [Kr]4d ⁷ 5s ¹	Rh Rhodium 102.90550 [Kr]4d ⁸ 5s ¹	Pd Palladium 106.42 [Kr]4d ¹⁰ 5s ⁰	Ag Silver 107.8682 [Kr]4d ¹⁰ 5s ¹	Cd Cadmium 112.411 [Kr]4d ¹⁰ 5s ²	In Indium 114.818 [Kr]4d ¹⁰ 5s ² 5p ¹	Sn Tin 118.710 [Kr]4d ¹⁰ 5s ² 5p ²	Sb Antimony 121.760 [Kr]4d ¹⁰ 5s ² 5p ³	Te Tellurium 127.60 [Kr]4d ¹⁰ 5s ² 5p ⁴	I Iodine 126.90447 [Kr]4d ¹⁰ 5s ² 5p ⁵	Xe Xenon 131.293 [Kr]4d ¹⁰ 5s ² 5p ⁶
6	Cs Cesium 132.90545 [Xe]6s	Ba Barium 137.327 [Xe]6s ²		Hf Hafnium 178.49 [Xe]4f ¹⁴ 5d ² 6s ²	Ta Tantalum 180.9479 [Xe]4f ¹⁴ 5d ³ 6s ²	W Tungsten 183.84 [Xe]4f ¹⁴ 5d ⁴ 6s ²	Re Rhenium 186.207 [Xe]4f ¹⁴ 5d ⁵ 6s ²	Os Osmium 190.23 [Xe]4f ¹⁴ 5d ⁶ 6s ²	Ir Iridium 192.222 [Xe]4f ¹⁴ 5d ⁷ 6s ²	Pt Platinum 195.078 [Xe]4f ¹⁴ 5d ⁹ 6s ¹	Au Gold 196.96655 [Xe]4f ¹⁴ 5d ¹⁰ 6s ¹	Hg Mercury 200.59 [Xe]4f ¹⁴ 5d ¹⁰ 6s ²	Tl Thallium 204.3833 [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 6p ¹	Pb Lead 207.2 [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 6p ²	Bi Bismuth 208.98038 [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 6p ³	Po Polonium (209) [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 6p ⁴	At Astatine (210) [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 6p ⁵	Rn Radon (222) [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 6p ⁶
7	Fr Francium (223) [Rn]7s	Ra Radium (226) [Rn]7s ²		Rf Rutherfordium (261) [Rn]5f ¹⁴ 6d ² 7s ²	Db Dubnium (262) [Rn]5f ¹⁴ 6d ³ 7s ²	Sg Seaborgium (266) [Rn]5f ¹⁴ 6d ⁴ 7s ²	Bh Bohrium (264) [Rn]5f ¹⁴ 6d ⁵ 7s ²	Hs Hassium (277) [Rn]5f ¹⁴ 6d ⁶ 7s ²	Mt Meitnerium (268) [Rn]5f ¹⁴ 6d ⁷ 7s ²	Uun Ununnilium (281) [Rn]5f ¹⁴ 6d ⁸ 7s ²	Uuu Ununnilium (282) [Rn]5f ¹⁴ 6d ⁹ 7s ²	Uub Ununnilium (285) [Rn]5f ¹⁴ 6d ¹⁰ 7s ²	Uuq Ununquadium (289) [Rn]5f ¹⁴ 6d ¹⁰ 7s ² 7p ¹	Uuh Ununhexium (292) [Rn]5f ¹⁴ 6d ¹⁰ 7s ² 7p ²				
			La Lanthanum 138.9055 [Xe]5d ¹ 6s ²	Ce Cerium 140.116 [Xe]4f ¹ 5d ¹ 6s ²	Pr Praseodymium 140.90765 [Xe]4f ³ 6s ²	Nd Neodymium 144.24 [Xe]4f ⁴ 6s ²	Pm Promethium (145) [Xe]4f ⁵ 6s ²	Sm Samarium 150.36 [Xe]4f ⁶ 6s ²	Eu Europium 151.964 [Xe]4f ⁷ 6s ²	Gd Gadolinium 157.25 [Xe]4f ⁷ 5d ¹ 6s ²	Tb Terbium 158.92534 [Xe]4f ⁹ 6s ²	Dy Dysprosium 162.500 [Xe]4f ¹⁰ 6s ²	Ho Holmium 164.93032 [Xe]4f ¹¹ 6s ²	Er Erbium 167.259 [Xe]4f ¹² 6s ²	Tm Thulium 168.93421 [Xe]4f ¹³ 6s ²	Yb Ytterbium 173.04 [Xe]4f ¹⁴ 6s ²	Lu Lutetium 174.967 [Xe]4f ¹⁴ 6s ²	
			Ac Actinium 227.0331 [Rn]5f ¹ 7s ²	Th Thorium 232.0377 [Rn]5f ¹⁴ 6d ² 7s ²	Pa Protactinium 231.03688 [Rn]5f ² 6d ¹ 7s ²	U Uranium 238.02891 [Rn]5f ³ 6d ¹ 7s ²	Np Neptunium (237) [Rn]5f ⁴ 6d ¹ 7s ²	Pu Plutonium (244) [Rn]5f ⁶ 7s ²	Am Americium (243) [Rn]5f ⁷ 7s ²	Cm Curium (247) [Rn]5f ⁷ 7s ²	Bk Berkelium (247) [Rn]5f ⁹ 7s ²	Cf Californium (251) [Rn]5f ¹⁰ 7s ²	Es Einsteinium (252) [Rn]5f ¹¹ 7s ²	Fm Fermium (257) [Rn]5f ¹² 7s ²	Md Mendelevium (258) [Rn]5f ¹³ 7s ²	No Nobelium (259) [Rn]5f ¹⁴ 7s ²	Lr Lawrencium (262) [Rn]5f ¹⁴ 7p ¹	

ased upon ^{12}C . () indicates the mass number of the most stable isotope.

For a description of the data, visit physics.nist.gov/data

NIST SP 966 (September 2003)

Electrons

- **Electron configuration of an atom**
 - how electrons are distributed among the various atomic orbitals (s, p, d, f) and energy levels
- **Valence/oxidation state**

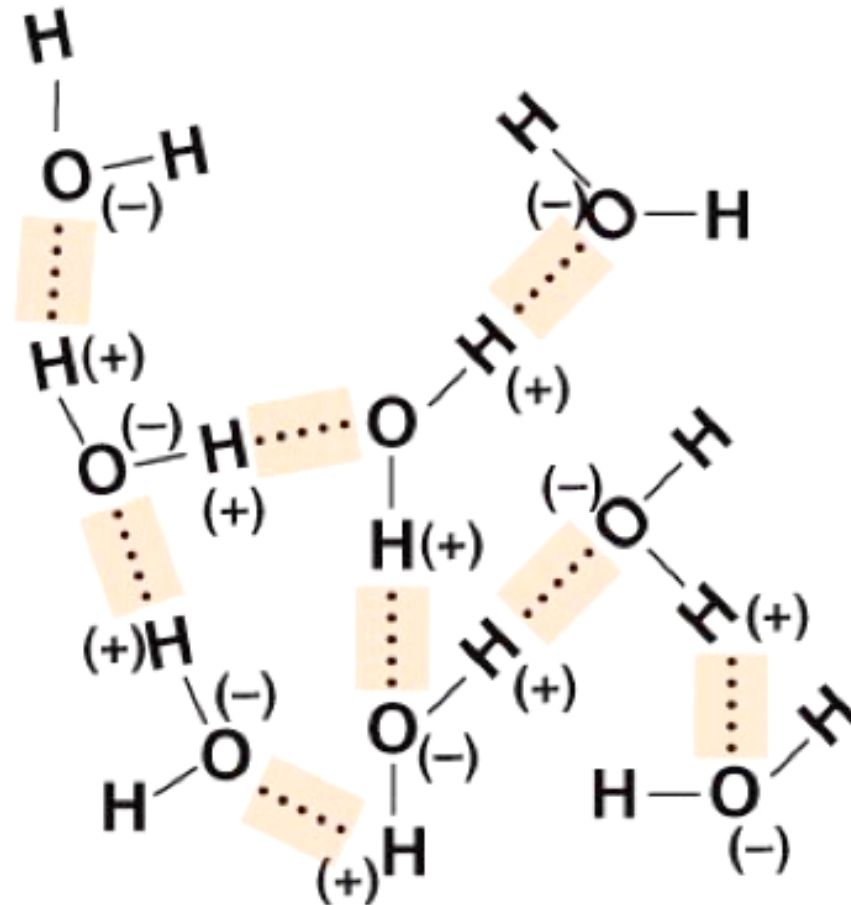
Molecules - compounds

- **Reactive atoms form molecules that are held together by chemical bonds**
- **Molecules with two or more different atoms are called compounds**
- **Molecular mass**
- **Monomers**
 - small molecules that are the building blocks of larger molecules
 - chemical elements bond in different combinations to form monomers
- **Polymers**
 - larger molecules composed of bonded monomers
- **Macromolecules**
 - larger molecules composed of covalently bonded polymers

Chemical bonds

- **Ionic bonds**
 - weak pH-dependent electrostatic interactions
 - support ionization in aqueous solutions
 - many important biomolecules (e.g., carboxylic acids, phosphates) are ionized at cytoplasmic pH
- **Covalent bonds**
 - strong bond, two atoms equally share electrons
- **Hydrogen bonds**
 - weak bond formed due to electrostatic interactions between hydrogen atoms and more electron-attracting (electronegative) atoms
 - impart considerable stability to molecules
 - play major roles in the biological properties of proteins
- **Van der Waals bonds**
 - weak attractive forces between atoms when they become closer than 3-4 Å
 - play important roles in enzymes binding substrates and protein–nucleic acid interactions

Hydrogen bonds between water molecules



More hydrogen bonds

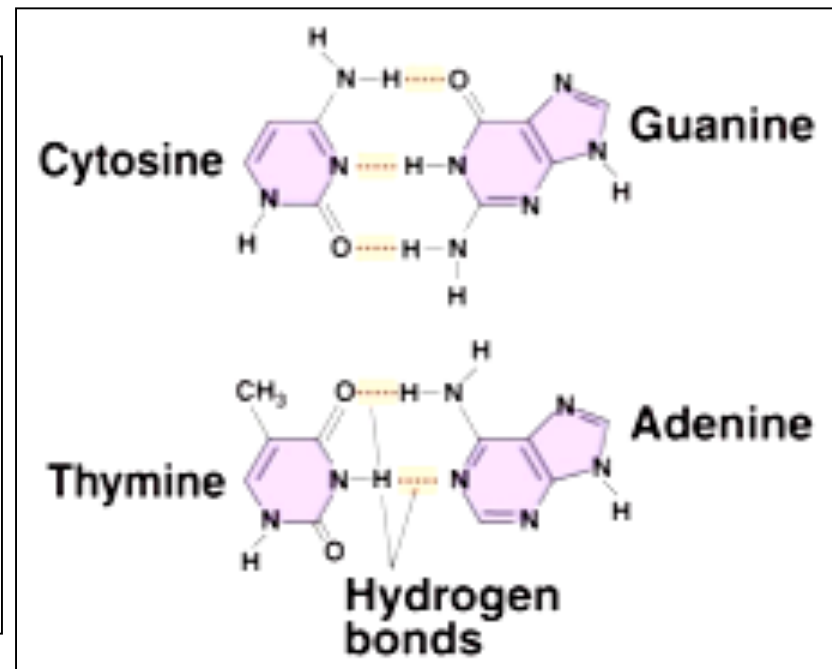
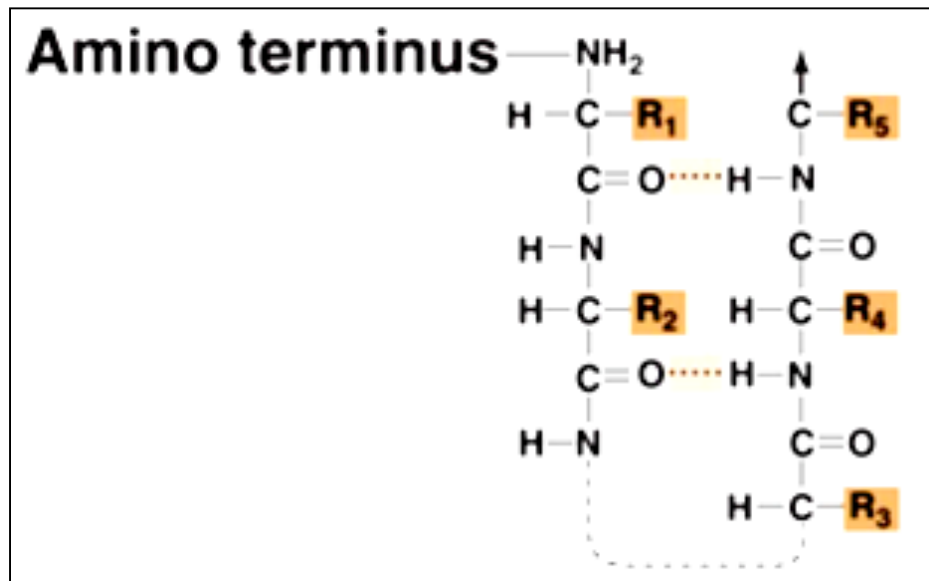


TABLE 1-1 Strengths of Bonds Common in Biomolecules

Type of bond	Bond dissociation energy* (kJ/mol)	Type of bond	Bond dissociation energy (kJ/mol)
Single bonds		Double bonds	
O—H	470	C=O	712
H—H	435	C=N	615
P—O	419	C=C	611
C—H	414	P=O	502
N—H	389	Triple bonds	
C—O	352	C≡C	816
C—C	348	N≡N	930
S—H	339		
C—N	293		
C—S	260		
N—O	222		
S—S	214		

*The greater the energy required for bond dissociation (breakage), the stronger the bond.

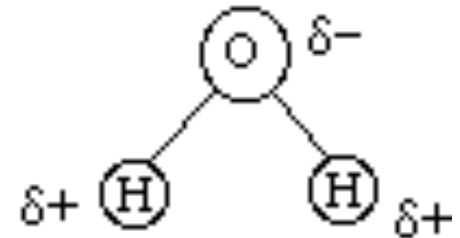
Chemical reactions

- **Reaction types of biological importance**
 - synthesis - new bonds are formed
 - decomposition - bonds are broken
 - exchange
- **Reversibility of chemical reactions**
 - energy requirements
 - endergonic and exergonic reactions
 - catalysis/biocatalysis

Biologically important molecules

- **Water**

- **polar molecule - polarity**
- **strong bonding between water molecules - cohesiveness**
 - high boiling point
 - strong density dependence on temperature
 - water is a solvent
 - water is a reactant or a product
 - water is a temperature buffer



Polarity

- **Polar**
 - possessing hydrophilic (“water-loving”) characteristics
 - generally water soluble
- **Non-polar**
 - possessing hydrophobic (“water-repelling”) characteristics
 - not water soluble

Why is polarity important?

- Many macromolecules are also polar and readily dissolve in water
- Promotes the stability of large molecules through hydrogen bonding
- Forces non-polar substances to aggregate
- Makes water cohesive

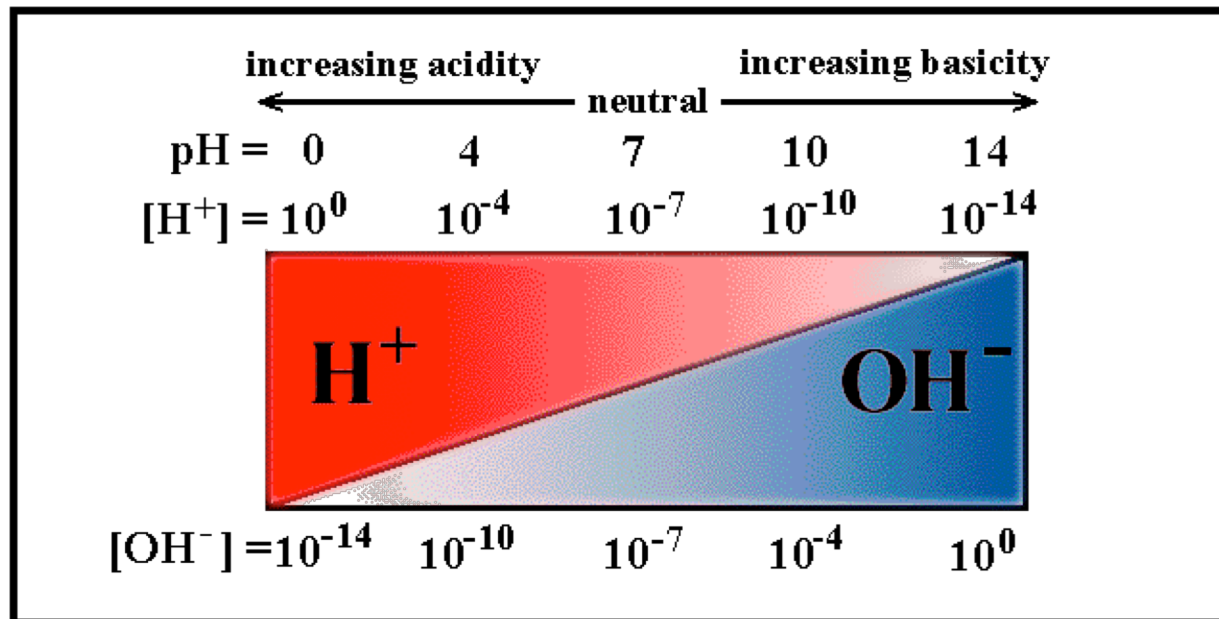
Hydrophobic interactions

- **Weak bonds**
 - non-polar molecules or non-polar regions of molecules associate tightly in a polar environment
- **Play important roles in**
 - enzymes binding substrates
 - protein conformation
 - stabilization of RNA and cell membranes

Acids and bases

- **Acid** - can donate a proton (H^+)
- **Base** - can accept a proton (H^+)
- **Salt** - cations and anions
- **pH**
- **Buffer** - composition that can prevent major pH changes

pH/pOH



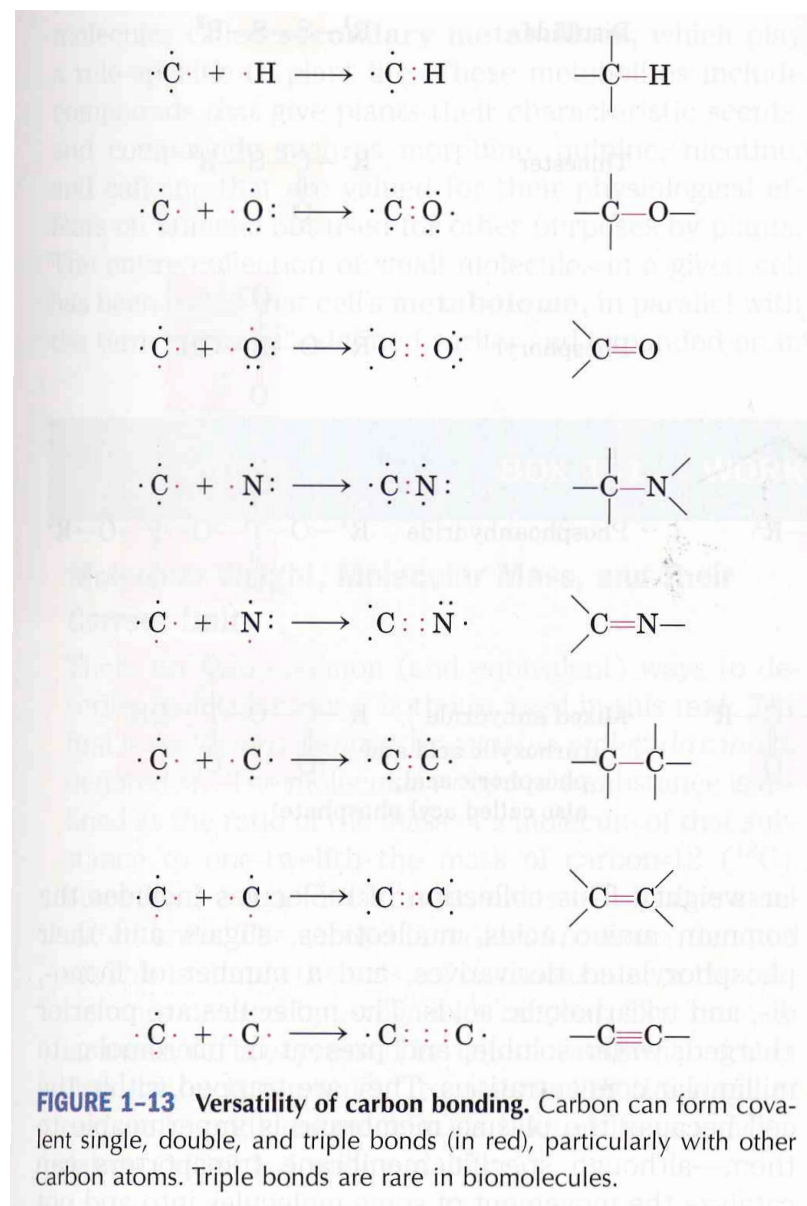
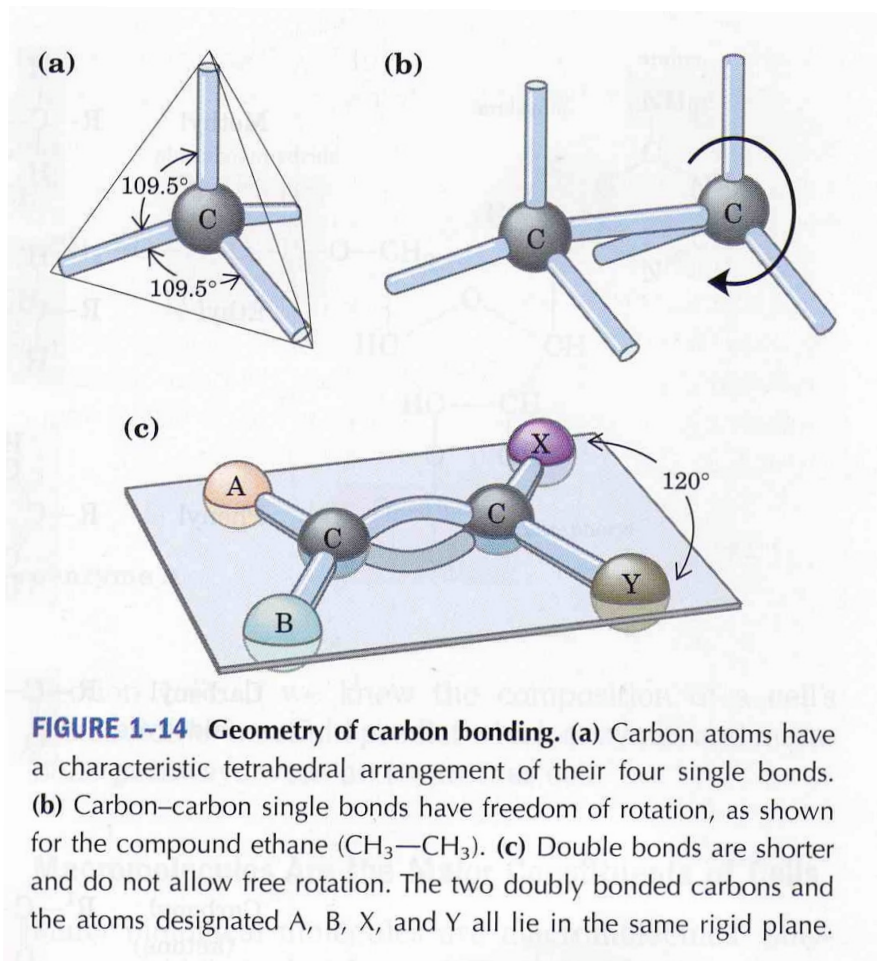
- Measure of hydrogen ion concentration in a solution
- $pH = -\log[H^+]$
- Example
 $[H^+] = 0.0001M,$
 $pH = -\log(0.0001) = -(-4) = 4$

Inorganic compounds

- **There is no life without water**
- **Biogeochemical processes**
- **Electron donors and acceptors**
- **Metal homeostasis**

Organic compounds

- **Carbon atoms can combine in an enormous variety of ways**
 - carbon skeleton (C, H)
 - functional groups (H, O, N, S, P, *etc.*)
 - their bonding patterns impart unique chemical properties to the compounds
- **Monomers build polymers**
- **Polymers form macromolecules**



Functional groups with biological importance

Table 3.1 Some functional groups of biochemical importance

Functional group	Structure ^a	Biological relevance	Example
Carboxylic acid	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{OH} \end{array}$	Organic, amino, and fatty acids; lipids; proteins	Acetate ^b
Aldehyde	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{H} \end{array}$	Functional group of reducing sugars such as glucose; aldehydes	Formaldehyde
Alcohol	$\begin{array}{c} \text{H} \\ \\ -\text{C}-\text{OH} \\ \\ \text{H} \end{array}$	Lipids; carbohydrates	Glucose
Keto	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}- \end{array}$	Citric acid cycle intermediates	α -ketoglutarate
Ester	$\begin{array}{c} \text{O} \quad \text{H} \\ \parallel \quad \\ -\text{C}-\text{O}-\text{C}- \\ \\ \text{H} \end{array}$	Triglycerides	Lipids of <i>Bacteria</i> and <i>Eukarya</i>

^aA squiggle-type bond depiction (-) indicates an "energy-rich" bond (see Section 5.8).

^bAcetate (H_3CCOO^-) is the ionized form of acetic acid (H_3CCOOH).

Functional groups with biological importance

Table 3.1 Some functional groups of biochemical importance

Functional group	Structure ^a	Biological relevance	Example
Phosphate ester		Nucleic acids	DNA, RNA
Thioester		Energy metabolism; biosynthesis of fatty acids	Acetyl-CoA
Ether		Certain types of lipids	Lipids of Archaea
Acid anhydride		Energy metabolism	Acetyl phosphate
Phosphoanhydride		Energy metabolism	Adenosine triphosphate (ATP)
Peptide		Proteins	Cellular proteins

^aA squiggle-type bond depiction (~) indicates an "energy-rich" bond (see Section 5.8).

^bAcetate (H_3CCOO^-) is the ionized form of acetic acid (H_3CCOOH).

Polysaccharides

- **Polymers of sugars**
 - sugars contain carbon, hydrogen, and oxygen at a ratio of 1:2:1
- **Monosaccharides - most biologically relevant contain 4–7 carbon atoms**
 - isomers - same molecular formula, but a different arrangement of the atoms in space
 - structural isomers - chain, position, functional group
 - cis/trans isomers (=geometrical isomers)
 - optical isomers (=chirality)
- **Disaccharides**
- **Oligosaccharides**

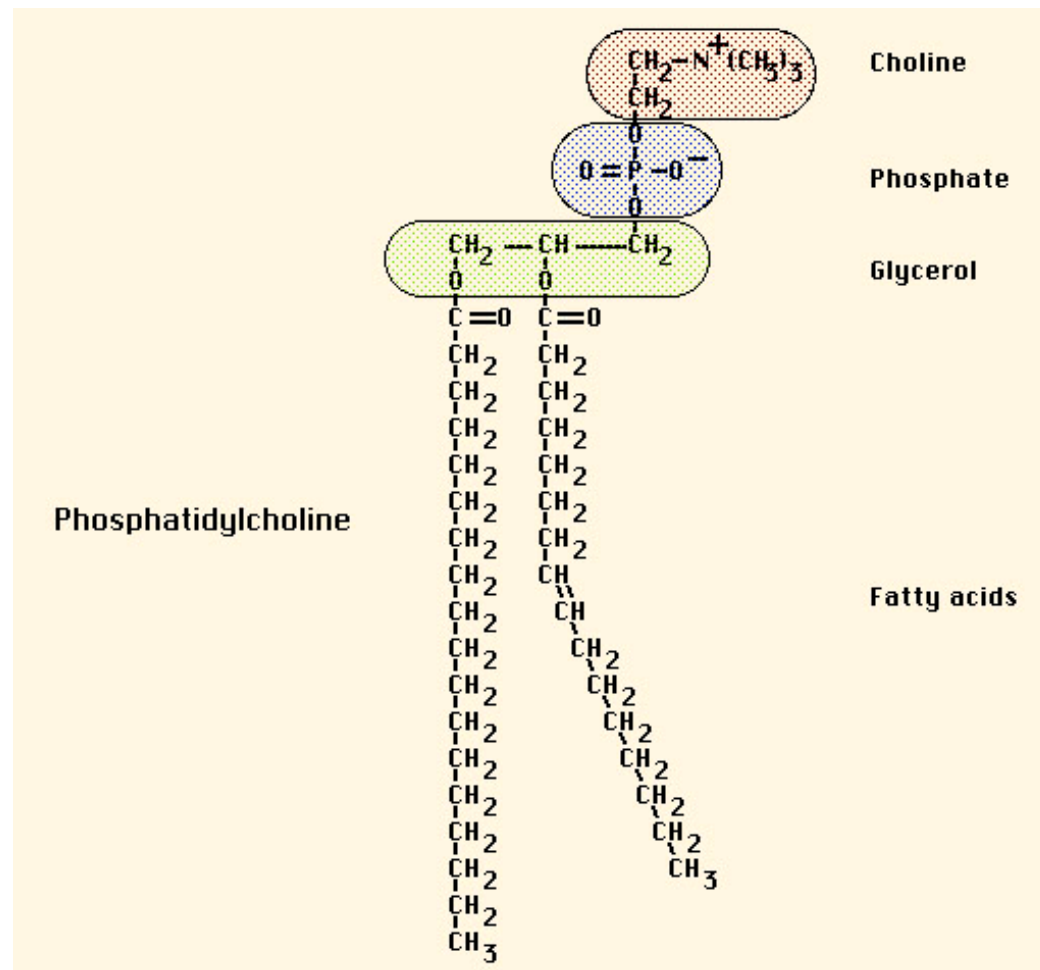
Polysaccharides

- Polysaccharides can combine with other classes of macromolecules to form **complex polysaccharides**
 - glycoproteins: polysaccharides + proteins
 - glycolipids: polysaccharides + lipids
 - cellular functions
 - cell-surface receptor molecules - typically reside on external surfaces of the membrane
 - glycolipids important in cell walls of gram-negative bacteria

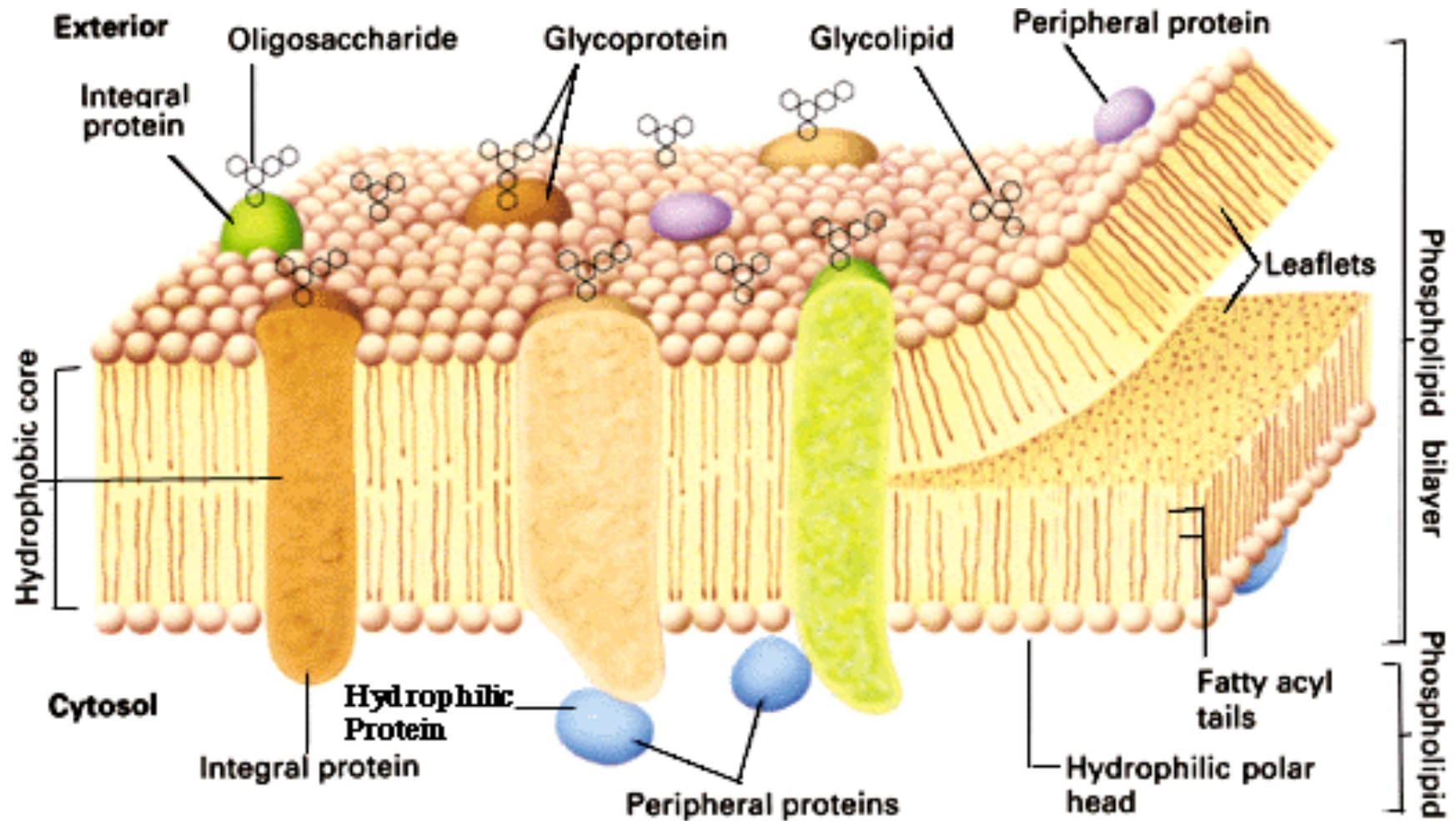
Lipids

- **Major group of organic compounds**
- **Biologically important lipids are amphipathic macromolecules**
 - possess hydrophilic and hydrophobic characteristics
- **Functions in living systems**
 - participate in membranes and cell walls
 - energy storage
- **Simple lipids**
 - glycerol + fatty acids
 - saturated/unsaturated
- **Complex lipids - neutral, polar, non-polar**
 - phospholipids
 - steroids and sterols

Phospholipids

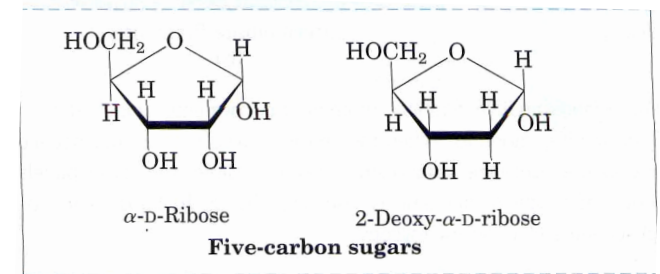


Plasma membrane



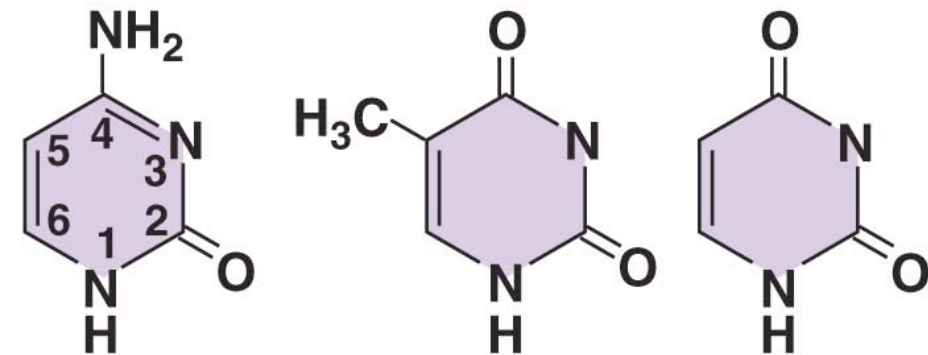
Nucleic acids

- Deoxyribonucleic acid (DNA)
- Ribonucleic acid (RNA)
- Nucleosides/nucleotides
 - bases
 - purines (adenine and guanine)
 - pyrimidines (cytosine and thymine/uracil)
 - deoxyribose/ribose
 - phosphate group



Bases in nucleic acids

Pyrimidine bases



Cytosine
(C)

Thymine
(T)

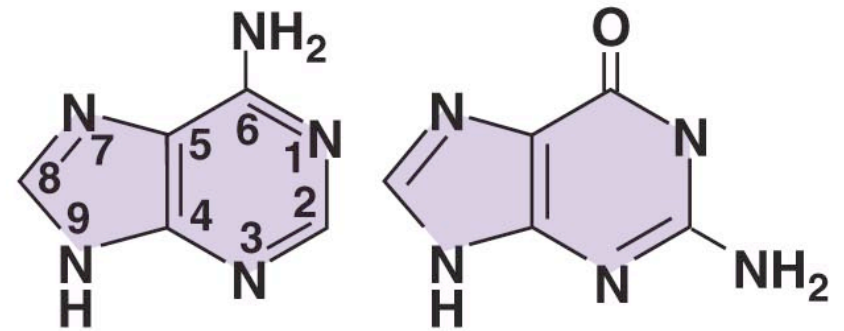
Uracil
(U)

DNA
RNA

DNA
only

RNA
only

Purine bases



Adenine
(A)

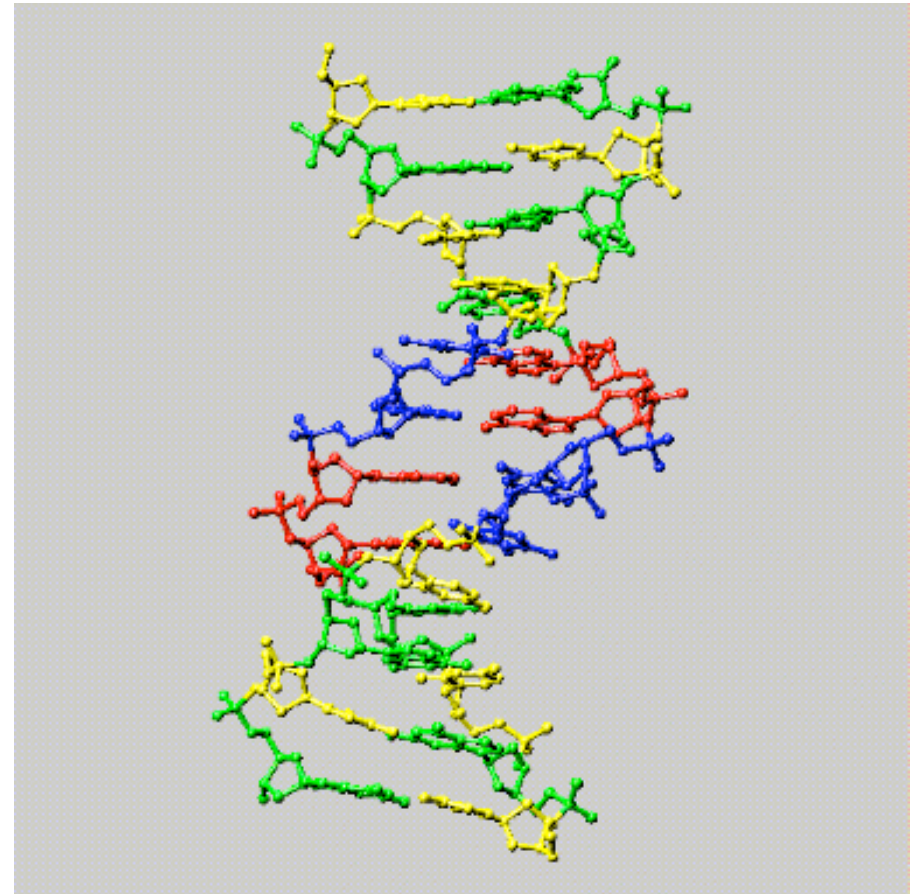
Guanine
(G)

DNA
RNA

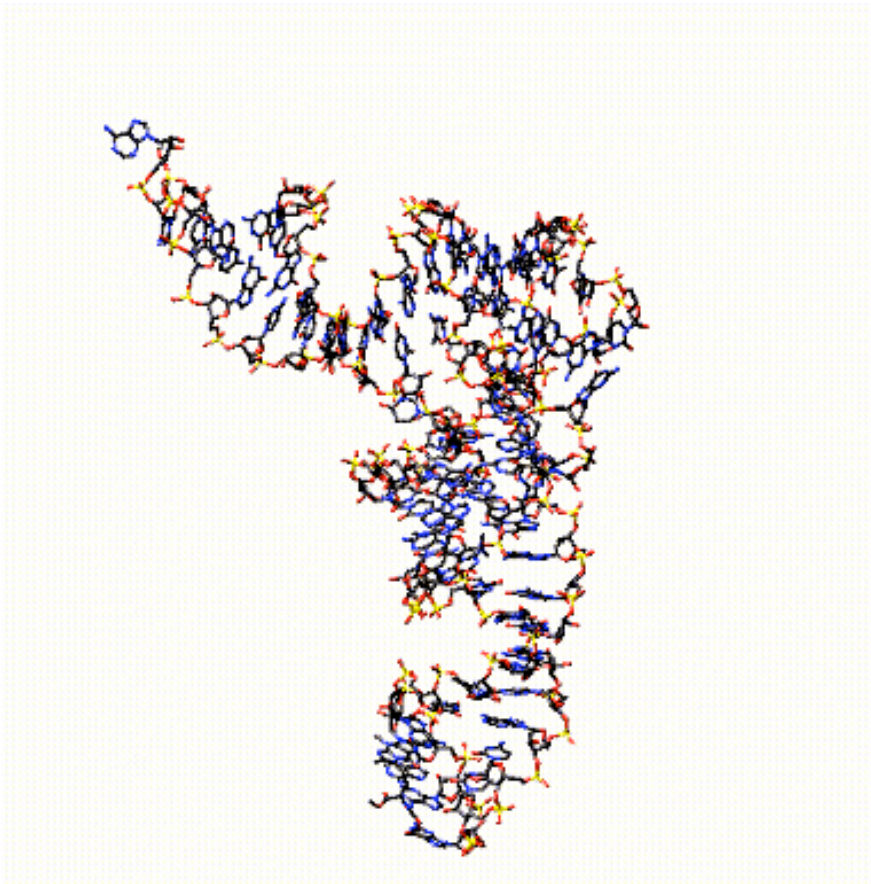
DNA
RNA

DNA

- **Linear polymer of nucleotides**
- **Nucleotide units connected via the 3' and 5' atoms of two neighboring sugars forming phosphodiester linkages**
- **Complementary pairing**
- **Duplex chain is anti-parallel**
- **Several conformations (B, A, and Z)**



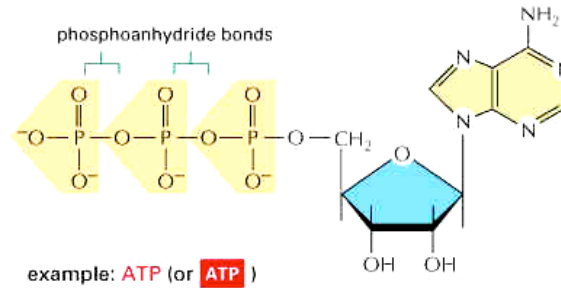
RNA



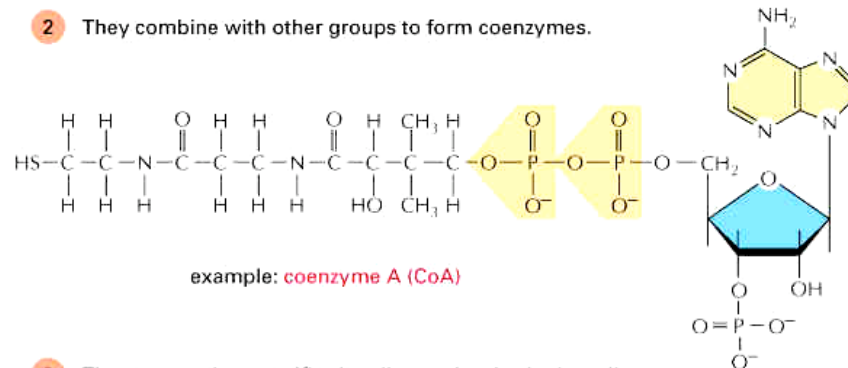
- Nucleic acid polymer that contains ribose
- Base composition contains uracil (instead of thymine)
- Typically single stranded and forms complex and unusual shapes
- Can form double helix - “A” conformation
- mRNA
- rRNA
- tRNA
- ribozyme
- small RNAs

NUCLEOTIDES HAVE MANY OTHER FUNCTIONS

- 1 They carry chemical energy in their easily hydrolyzed phosphoanhydride bonds.

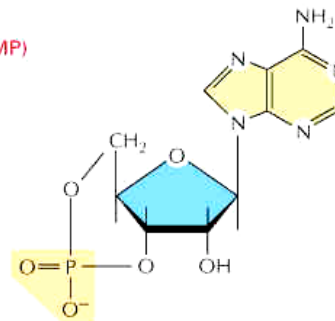


- 2 They combine with other groups to form coenzymes.



- 3 They are used as specific signaling molecules in the cell.

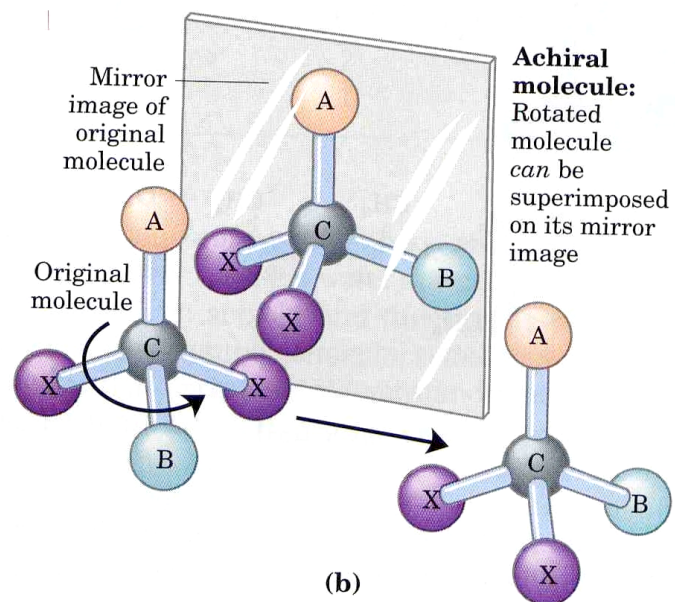
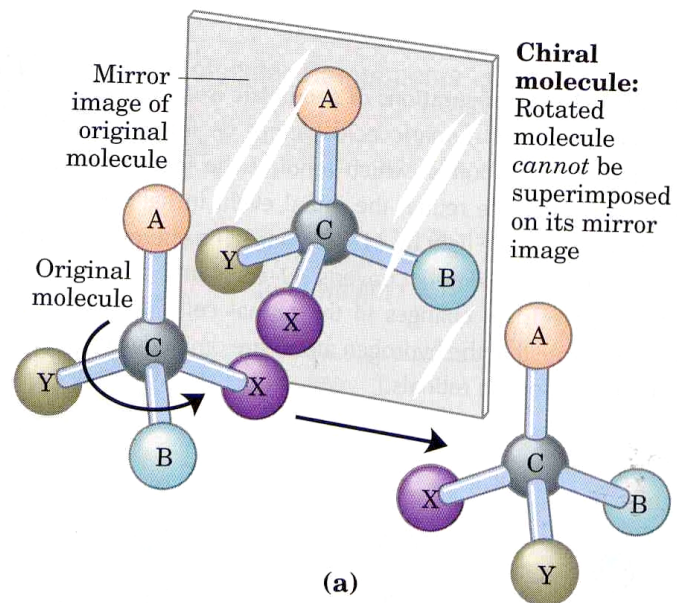
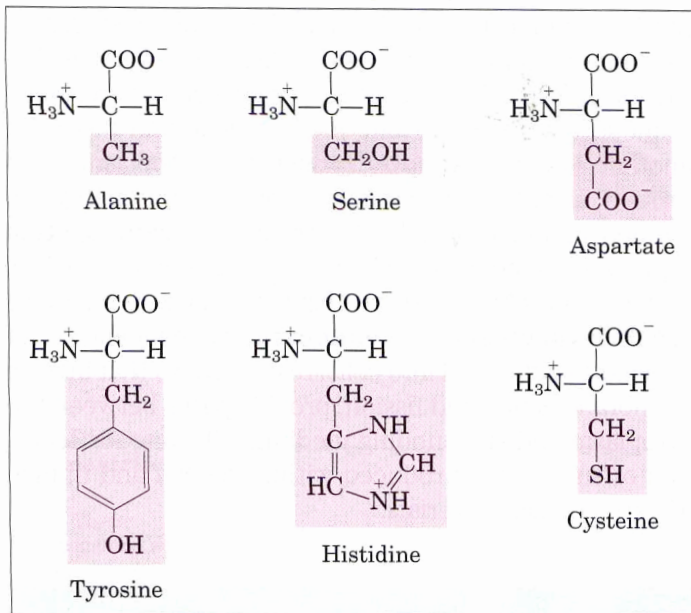
example: **cyclic AMP (cAMP)**



Amino acids

- **Building blocks of proteins**
- **Amino (-NH₂) and carboxyl groups (-COOH)**
- **R can be**
 - H
 - unbranched or branched chain
 - cyclic or heterocyclic
 - functional groups
- **Stereoisomer configuration**
- **22 amino acids found in proteins (2 contain sulfur, 1 selenium)**

(a) Some of the amino acids of proteins



References and Notes

1. N. P. Kristensen, in *The Hierarchy of Life. Molecules and Morphology in Phylogenetic Analysis*, B. Fernholm, K. Bremer, H. Jönvall, Eds. (Elsevier, Amsterdam, 1989), pp. 295–306.
2. ———, in *The Insects of Australia*, CSIRO, Ed. (Melbourne Univ. Press, Carlton, ed. 2, 1991), vol. 1, chap. 5.
3. A. H. Staniczek, *Zool. Anz.* **239**, 147 (2000).
4. In June 2001, J. Marshall (Natural History Museum, London) showed O.Z. a male insect from Tanzania, which had been submitted for an opinion 16 years ago. Shortly afterward O.Z. received from F. Kernegger a male Baltic-amber insect (subsequently described as *Raptophasma kerneggeri*), whose close similarity to the Tanzania specimen was immediately obvious. In July 2001, O.Z. discovered in the unsorted alcohol collection of Phasmatodea in the Museum für Naturkunde (Berlin) an adult female of a similar insect from Namibia.
5. According to one school of thought among contemporary systematists, the naming of higher taxa that only contain a single genus is “empty formalism”; we accept the logical merits of this stand. Pragmatically we believe, however, that any recognized genus should be assigned to a “family” and an “order,” because these categories play an important role in how biologists communicate and how biological knowledge is systematized.
6. The description includes many characters currently known only from a single specimen, because genitalic characters can only be observed in a specimen of the respective sex, muscle characters can only be observed in the ethanol-preserved female, and only a few characters can be judged in the *Raptophasma* fossils.

REPORTS

Pyrrolysine Encoded by UAG in Archaea: Charging of a UAG-Decoding Specialized tRNA

Gayathri Srinivasan, Carey M. James, Joseph A. Krzycki*

Pyrrolysine is a lysine derivative encoded by the UAG codon in methylamine methyltransferase genes of *Methanosarcina barkeri*. Near a methyltransferase gene cluster is the *pylT* gene, which encodes an unusual transfer RNA (tRNA) with a CUA anticodon. The adjacent *pylS* gene encodes a class II aminoacyl-tRNA synthetase that charges the *pylT*-derived tRNA with lysine but is not closely related to known lysyl-tRNA synthetases. Homologs of *pylS* and *pylT* are found in a Gram-positive bacterium. Charging a tRNA_{CUA} with lysine is a likely first step in translating UAG amber codons as pyrrolysine in certain methanogens. Our results indicate that pyrrolysine is the 22nd genetically encoded natural amino acid.

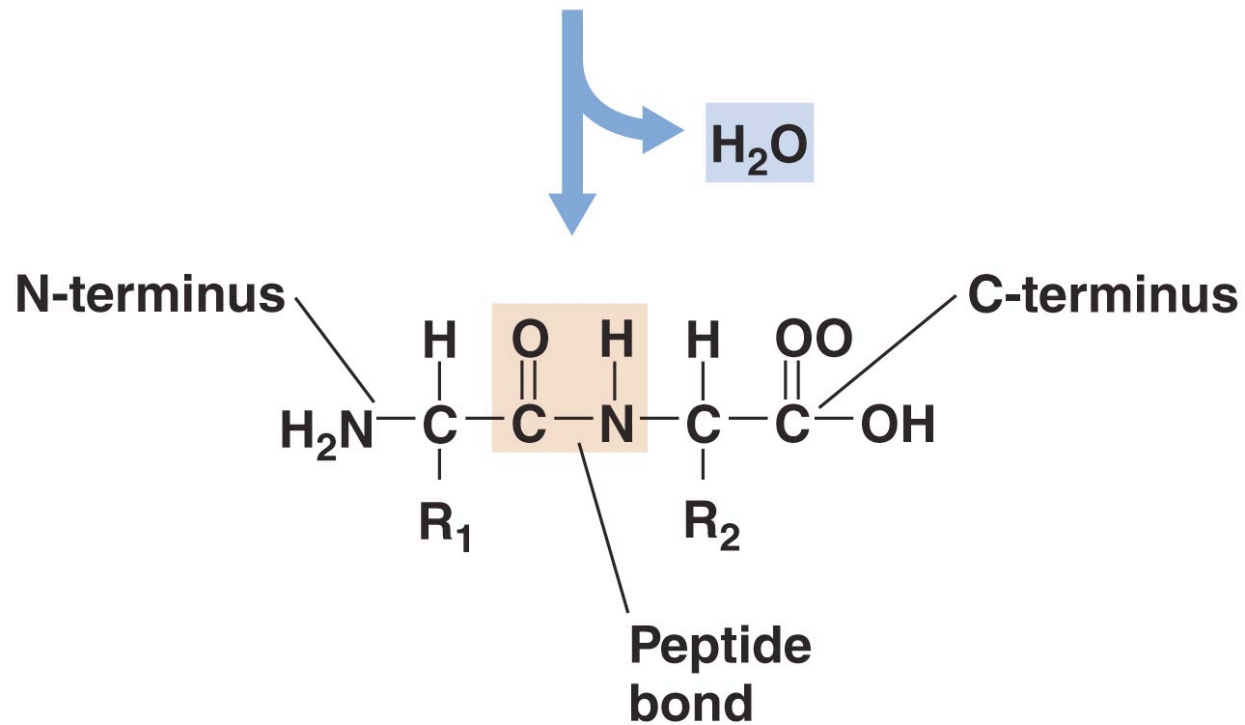
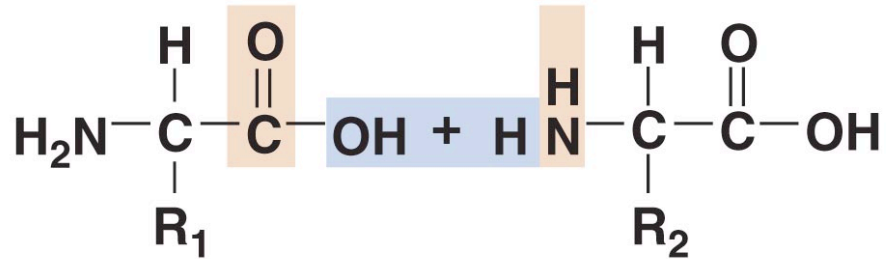
In *Methanosarcina* species, specific methyltransferases initiate methanogenesis and carbon assimilation from substrates such as trimethylamine (TMA), dimethylamine (DMA), or monomethylamine (MMA). The

pool from MMA-grown *M. barkeri* MS revealed an RNA of the size expected for the tRNA_{CUA} product of *pylT* (Fig. 1C). The predicted secondary structure of tRNA_{CUA} has unusual properties compared

Proteins

- **Can be more than 50% of cell dry weight**
- **Essential structures/functions**
 - structural proteins (S-layers, cell walls, membranes, cytoskeleton)
 - signal, receptor, and transport proteins
 - regulatory proteins
 - enzymes
 - toxins, antimicrobial proteins
 - in higher organisms hormones, antibodies
- **Peptide bonds - covalent bond**
- **Polypeptides**

Peptide bond formation



Protein folding/ structure and function

- **Primary structure**
 - linear array of amino acids in a polypeptide
- **Secondary structure**
 - folds in polypeptide that form a more stable structure, often involving hydrogen bonding between R groups

Protein folding/ structure and function

- **Tertiary structure**
 - **additional folding of polypeptide to result in greater stability and unique three-dimensional shape**
 - **forms exposed regions or grooves in the molecule that are important for binding other molecules**
 - **disulfide bonds**
 - **bonds between -SH groups from two different amino acids**

Protein folding/ structure and function

- **Quaternary structure**
 - occurs in proteins composed of two or more polypeptides
 - subunit
 - each polypeptide in the protein, held together by either/both covalent and non-covalent linkages
 - homodimer
 - protein containing two identical subunits
 - heterodimer
 - protein containing two non-identical subunits